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Optics, Acoustics, and Stress in a Nearshore Bottom Nepheloid Layer (OASIS)

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LONG-TERM GOALS

To quantify and understand the effects of aggregation dynamics on the distribution of particles in the bottom boundary layer, and to understand how the properties of particles (composition, shape, and internal structure) affect their optical and acoustical properties.

OBJECTIVES

- Obtain a set of acoustical and optical measurements that determines the evolution of the particle size distribution.

- Obtain concurrent velocity, temperature and conductivity measurements sufficient to determine the fluid dynamical environment within which the particle size distribution evolves.

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- Evaluate and improve a state-of-the-art model of particle dynamics by comparing model calculations with measurements.

APPROACH

The approach is to obtain measurements that will permit comparisons of the optical and acoustical signatures of suspended particles and inferences of the particle size distribution and its temporal evolution, concurrently with fluid dynamical measurements that determine the flow field within which the particles evolve. The instrumentation is mounted on bottom tripods and includes a 9-wavelength optical attenuation and absorption meter (WetLabs ac-9, with automated regular dissolved measurement for calibration independent particulate measurements), a LISST-100 laser diffraction particle sizer (Agrawal & Pottsmith 2000), a digital floc camera (DFC) (Curran et al. 2002b), a Tracor Acoustic Profiling System (TAPS, Holliday 1987), and an array of SonTek/YSI acoustic Doppler velocimeters (ADVs) . Near-simultaneous measurements with and without a filter assure high-quality particulate spectral absorption and attenuation measurements with the ac-9. The LISST-100 and floc camera together provide particulate size distributions from 2.5 micrometers to 1 centimeter. The TAPS obtains range-gated, vertical profiles of acoustical backscatter intensity at a range of frequencies between 0.3 and 3.0 MHz. The TAPS and ADVs produce acoustical measurements over a wide range of frequencies that can be used to generate particle size distributions (Holliday, 1987; Hay and Sheng, 1992). The combined optical and acoustical measurements will provide a comprehensive description of the suspended particles near the seabed. The velocity measurements obtained from the ADVs will provide direct-covariance estimates of Reynolds stress and inertial-range estimates of the dissipation rate for turbulent kinetic energy (Trowbridge 1998, Trowbridge & Elgar 2001, Shaw & Trowbridge 2001, Trowbridge & Elgar 2003).

The analysis includes estimation of Reynolds stress, dissipation rate, and eddy diffusivity; estimation of particle size distribution and concentration from the DFC and LISST-100; and estimation the optical and acoustical properties of the water column from analysis of the ac-9, TAPS, and ADV data. The analysis focuses on evaluation and improvement of a one-dimensional (vertical), time-dependent model of the particle size and concentration fields and the accompanying optical and acoustical properties. The model includes the effects of sediment resuspension by bottom shear stresses produced by waves and currents, vertical transport of suspended particles by turbulence, gravitational settling of particles, and particle aggregation and disaggregation.

WORK COMPLETED

Three sets of measurements have been obtained, the first during August-September 2004, the second during August-September 2005, and the third during August-September 2007. A fourth set of measurements is currently underway (September 2009). All four sets of measurements have occurred at the Martha's Vineyard Coastal Observatory (MVCO), which is operated by the Woods Hole Oceanographic Institution (WHOI). The MVCO, off the southern coast of Martha's Vineyard, Massachusetts, is a cabled observatory consisting of a shore station, a meteorological mast on the beach, a seafloor node at a water depth of 12 m, and an air-sea interaction tower (ASIT) at a water depth of 15 m. Atmospheric measurements are obtained routinely at the meteorological mast and the ASIT. Routine oceanic measurements of temperature, salinity and velocity are obtained at the 12-m node and the ASIT. The 2004 measurements for this study were obtained near the ASIT and the 2005 and 2007 measurements were obtained near the 12-m node. The 2007 program included measurements obtained from a profiler deployed by WetLabs.

RESULTS

Analysis of OASIS measurements has focused on characterization of the near-bottom flow environment in which the suspended particles exist and evolve. The flow characterization includes quantitative estimates of the bottom stress, dissipation rate, and mean shear. The measurements indicate a production-dissipation balance in the turbulent kinetic energy equation and excellent agreement with the Prandtl-Karman law of the wall, as expected in an un-stratified shear flow (Figure 1). A primary result of the analysis is estimates of the stress associated with the hour-averaged current and the standard deviation of the stress produced by surface gravity waves (Figure 2). The analysis indicates good agreement between measured hour-averaged stresses and corresponding stresses estimated from a boundary layer model, and much larger oscillatory stresses produced by surface gravity waves. Work in progress addresses the relationship between the stresses and the characteristics and concentration of the suspended particles. Additional work has addressed the interaction between turbulence and suspended organisms (Jumars et al. 2009) and the effect of breaking waves and Langmuir circulations on water-column turbulence (Gerbi et al. 2009, Kukulka et al. 2009).

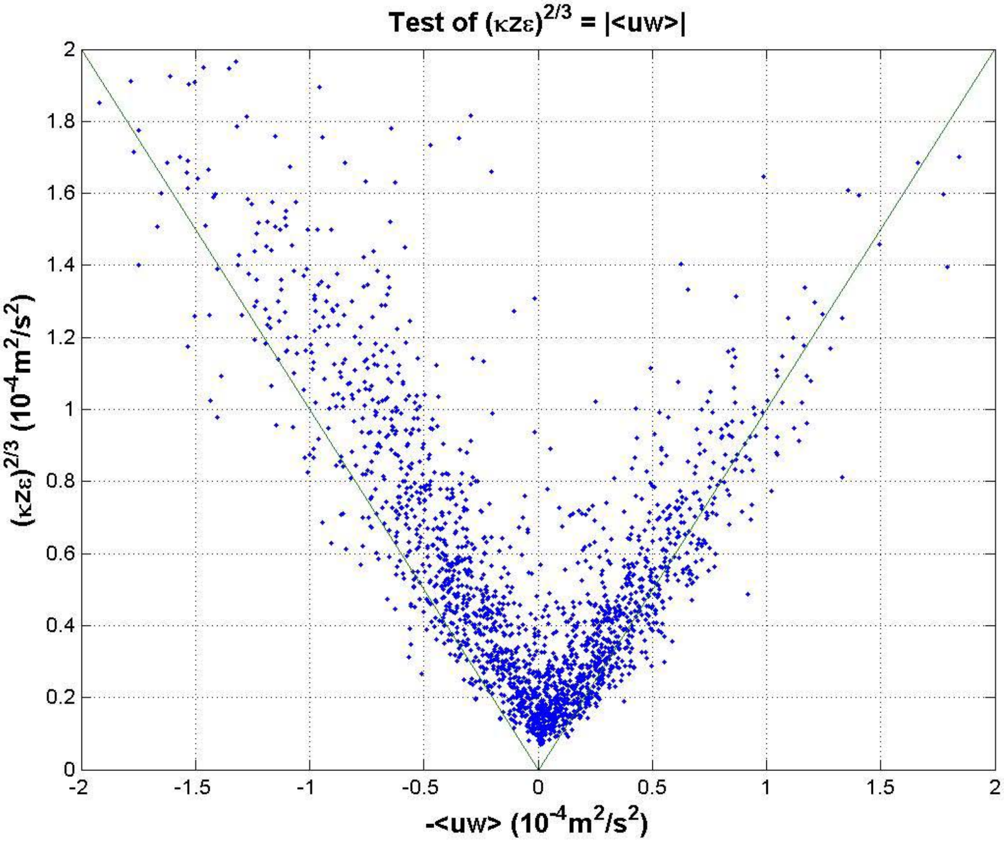

Figure 1. A test of the relationship** $(\kappa z\varepsilon)^{2/3} = |<uw>|$ **based on the 2007 OASIS measurements at the Martha's Vineyard Coastal Observatory. Here** $\kappa \approx 0.40$ **is the Karman constant,** z **is the distance above the bottom,** ε **is the hour-averaged energy dissipation rate per unit mass, and** $-\rho < uw >$ **is the turbulent Reynolds shear stress, where** ρ **is the fluid density,** u **and** w **are the streamwise and vertical turbulent velocity fluctuations, and brackets denote an hour average. The relationship** $(\kappa z\varepsilon)^{2/3} = |<uw>|$ **holds if the hour-averaged velocity varies logarithmically with height and if shear production of turbulent kinetic energy balances dissipation, as in a classical unstratified wall layer.

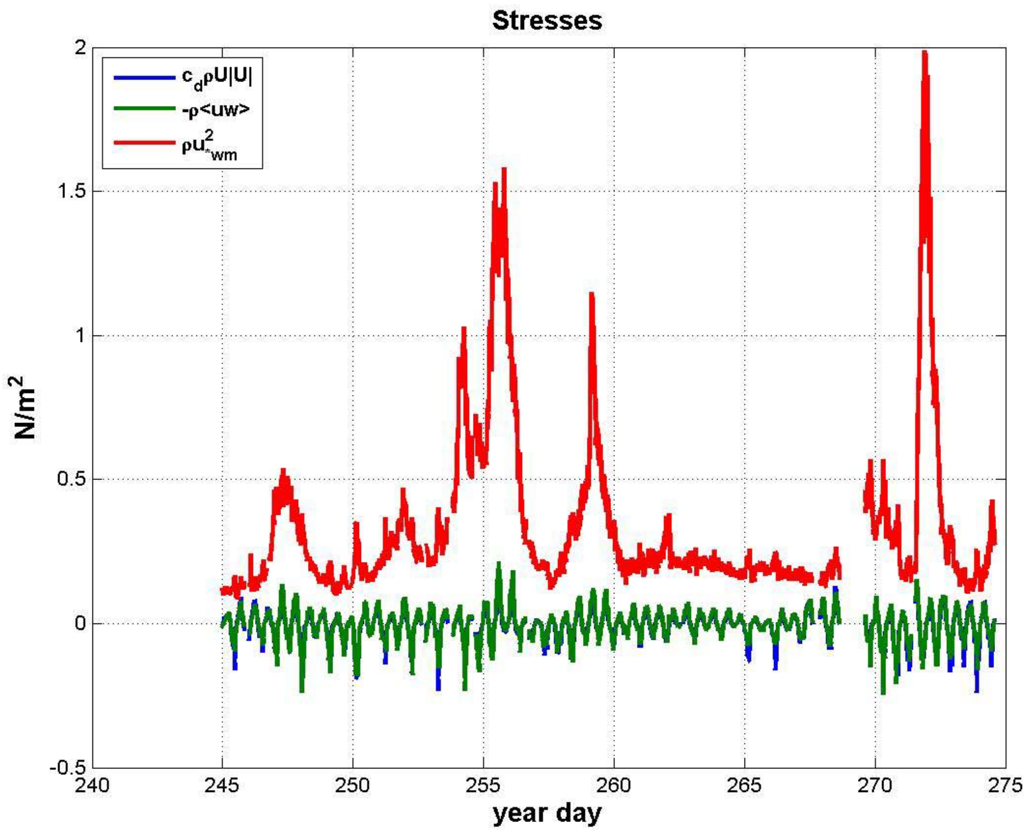

Figure 2. Stresses estimated from the 2007 measurements at the Martha's Vineyard Coastal Observatory. The directly measured hour-averaged Reynolds shear stress $-\rho < uw >$ agrees well with the drag-law estimate $c_d \rho |U| U$ inferred from the measured burst-averaged velocity U by means of an empirically determined drag coefficient c_d . The standard deviation $\rho u_{*wm}{}^2$ of the oscillatory bottom shear stress produced by surface waves is inferred from a wave-current interaction model and is much larger than the hour-averaged stress $-\rho < uw >$, which is associated with wind-driven and tidal currents. The wave-induced stress is primarily responsible for suspending particles and controlling the size of water-borne flocs.

IMPACT/APPLICATIONS

Operational seagoing systems often depend on optical and acoustical properties of suspended particles in the water column. Understanding the processes that regulate the particle characteristics and understanding the optical and acoustical signatures of suspended particles are essential in order to predict the performance of these operational systems.

RELATED PROJECTS

Mechanisms of Fluid-Mud Interactions under Waves, an ONR-funded MURI project aimed at understanding the dissipation of surface gravity waves over muddy seafloors. This combined field, laboratory, numerical, and theoretical study has been undertaken by S. J. Bentley (Memorial

University), R. A. Dalrymple (Johns Hopkins University), G. C. Kineke (Boston College), C. C. Mei (Massachusetts Institute of Technology), P. Traykovski (Woods Hole Oceanographic Instituion), J. H. Trowbridge (WHOI), and D. Yue (MIT). Companion field and analysis studies are being carried out by S. Elgar (WHOI), B. Raubenheimer (WHOI), T. Herbers (Naval Postgraduate School), and A. Sheremet (University of Florida). A focus of the WHOI, Boston College, and Memorial University field work is quantitative imaging and interpretation of the near-bottom mud dynamics that control energy dissipation.

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